ACCIDENT INVESTIGATION AT THE SWISS STEINGLETSCHER INSTALLATION

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ABSTRACT

An accidental detonation caused the total destruction of the Swiss Steingletscher installation and resulted in six fatalities on November 2, 1992. The facility, operated by a Swiss Army munitions factory, was used to store HE and LE explosives and obsolete ammunition prior to their disposal at the Swiss Alps. The Swiss DOD personnel have been working on the documentation of the event since its occurrence in 1992. The planned investigation consisted of four main tasks, namely: (1) development of debris density maps; (2) checking models in TLM 75; (3) estimation of the quantity of stored explosives; (4) final investigative report.

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The unfortunate incident at the Steingletscher installation provided the USAF (YOX) the opportunity to acquire "real" data from a full scale event and at the same time assist the Swiss military authorities in their investigation of the mishap. This paper provides an update of the work completed to date by the Swiss authorities and the manner in which the Bakhtar Explosives Safety Criteria, developed under the US DOD SBIR Phases I and II for the US Air Force, was used to estimate the TNT equivalent weight of the explosives which caused the event.

BACKGROUND

The accidental detonation of the Swiss munitions storage facility, Steingletscher installation shown Figure 1, provided a unique opportunity not only to the Swiss military authorities but also the US Air Force (YOX) to acquire real data from a full scale event. It should be pointed out that in Switzerland the safety of munitions storage facilities and handling of explosives in the military sector is assessed on the basis of a quantitative risk analysis approach (Kummer, 1993). The accident at the Steingletscher installation confirmed the applicability of the concept to such events. However, the technical data for the risk analysis, particularly, those of interest for the effect analysis, have been limited in its scope to a very limited amount of real information. Therefore, the mishap which was presented by the tragic event at the Swiss Alps was taken as an opportunity to extract maximum amount of real information from in order to improve the storage concept. As a result the Swiss Department of Defense personnel have been working towards full documentation of the filed data and event evaluation since its occurrence in the late 1992. More details on the Swiss safety concept was presented earlier (Bienz / Kummer / Swiss DoD, 1993). In general, positive experience was gained by the Swiss with their safety concept for the last two decades to the extend that several military and civilian agencies in the other countries adopted the approach with only minor modifications.

This paper provides an overview of the event and an update of the work completed to date by the Swiss authorities. It further elaborates on the manner in which assistance was provided by the US Air Force (YOX) to collect site specific data on characteristics of the engineered and geologic systems at the accident site. The acquired field information provided the necessary preliminary input data to the Bakhtar Explosives Safety Criteria, developed under the U.S. Air Force SBIR Phases I and II programs, to estimate the TNT equivalent weight of the explosives which caused the event.

INTRODUCTION

The obsolete ammunition in Switzerland is disassembled by specialists in one of the ammunition factories of the Swiss Military Administration. Propellants and pyrotechnic materials are burnt, the explosive parts are transported to a disposal site in the Swiss Alps and detonated by trained personnel (Figure 2).

Prior to the 1970s, the obsolete explosives were stocked in magazines located in the ammunition factories where they were manufactured. Annually, stocks of the unwanted explosives as well as obsolete ammunition were transported with trucks to the disposal site located in Steingletscher (which means "stone-glacier"). The truck delivery usually took place during the late autumn over a distance of 100 km through densely populated areas. Geographically, the facility was located in a side valley of an alpine pass, that connects the city of Interlaken with the Gotthard Valley, one of the most important north-to-south routes in Europe, at an elevation of approximately 2,040 m above the sea level (Figure 3). The site was surrounded by mountains with the nearest inhabited building 1.5 km away. A plateau with 0.5 km^2 existed in front of the portal which was used as the staging area for ordnance disposal. A frozen lake and a glacier system which have been formed by the recrystallization of snow created an interesting tourist attraction and a narrow road crossing the original entrance to the magazine provided public access to the lake and another view platforms on the high mountain.

In order to reduce the risks and at the same time provide safer working conditions at the factories within the ten month between the subsequent disposal campaigns, the Swiss authorities decided to construct an underground magazine few hundred meters away from the disposal site. The goal for construction of such a facility was to enable the obsolete explosives to be transported to the disposal site continuously throughout the year except during the winter season where the connecting road becomes closed to the through-going traffic because of the excessive snow falls.

It should be pointed out that the probability of an accidental detonation is greater for materials being prepared for disposal than those boxed for handling and transportation by the troops or long-term storage. Furthermore, there has not been an accidental detonation in an ammunition magazine in Switzerland for over five decades except for a small above-ground event caused by a sabotage.

THE "STEINGLETSCHER" MAGAZINE

Figures 4 and 5 show the plan and sectional views of the magazine before the accident, respectively. The engineered system consisted of the following components

- Personnel Quarter
- Utility Building
- Portal
- Access Tunnel
- Loading Ramp
- Unloading Area
- Chamber 1
- Chamber 2

The "log-book," in which details of the daily explosives inventory were recorded, was destroyed during the accident. Therefore, the TNT-equivalent weight of the explosives which is crucial for the investigation of the event on the day when the accident occurred is not available. Estimates based on recorded inventory in days prior to the accident indicated an equivalent TNT weight in excess of 200 tons corresponding to a loading density of almost 40 kg/m^3 for explosive compounds stored within the two chambers.

THE EVENT - NOVEMBER 2nd, 1992

On the day of accident, usual operations have been underway continuously for two weeks. At the moment of the accident six persons were working inside the chamber and eleven on the disposal area. At 4:13 p.m. on November 2nd 1992, seismological stations in Switzerland and northern Italy recorded the arrival of a series of major seismic waves (ground shocks) equivalent to magnitude 3.7 on the Richter scale. Five to ten seconds before, a fire in one of the chambers was reported which probably resulted in detonation of the stored explosives. Therefore, the source for the recorded events at the seismological stations was the internal detonation within the engineered system of the Steingletscher installation. A possible scenario leading to the explosion is depicted in a report by Kummer (1993). This report, with limited distribution, was prepared for presentation at the 18th KLOTZ Club Meeting which was hosted by the Swedish Representatives in Stockholm, Sweden.

Following the blast, the installation was destroyed completely, six persons working inside the facility were killed, the cover was broken into fly-rock pieces which were thrown to various distances from the portal. The large crater, developed post blast, was partially filled with by the loosened rock pieces falling off the steep slope formed behind the back of the destroyed magazine (Figures 6 and 7). Blocks of debris, up to 20 tons concrete, were thrown to distances of around 600 m (Figure 8) and stopped by the high terrain exhibited locally. Fortunately, non of the personnel working outside the structure was injured.

SUMMARY OF WORK COMPLETED TO DATE

i) EFFORTS BY THE SWISS MILITARY ADMINISTRATION

The Swiss Defence Technology and Procurement Agency personnel and their technical consultants have been working on the documentation of the event since it occurrence in November 1992. The possible sequence of event leading to the accidental detonation inside the explosives storage facility is still under investigation by the Swiss authorities. The site investigation tasks were somewhat impeded by the heavy snow at the site (Swiss Alps). In addition, the legal investigation took precedent over the technical tasks, and so the combination of the two resulted in an almost seven month delay before the site investigation actually started in July 1993. However, in August 1993, the troops were ordered to clean the area and the investigative crew were given a short time to collect the necessary field data. The priority for the field investigation was given to collecting debris thrown from the access tunnel and fragments originated from the magazine. The following procedures were followed to accomplish these tasks:

- Debris in excess of one ton were identified and mapped (Figure 9).

- Objects located (total of 53) were marked with white paint to ease their identification on the aerial photograph.

- Debris located were carefully measured for their dimensions and special features noted.

- Forty representative areas (20 to 150 m^2) were selected and all debris which fall within these patches were recovered and their dimensional as well as their apparent characteristics were noted (Figure 10). The contrast which existed at the site between the background and blast-induced fragments facilitated the ease of debris identification during the recovery operations (Figure 11). The recovered debris are now being used to develop the debris density contour maps.

Another task was to construct a new topographic map of the site showing the post event new contour lines of the surface. In order to accomplish this task, aerial photographs were taken from an altitude of 1000 m. This task is now completed and results are shown in Figure 12. This figure shows the exact location of the accident site as well as the 53 identified objects (using circle marks) and 40 debris collection areas (using rectangle marks).

(ii) EFFORTS CONTRIBUTED BY THE US AIR FORCE (YOX)

The Swiss authorities planned investigation included:

- Development of debris density maps.

- Checking models in the TLM 75.

- Estimation of the quantity of stored explosives.

- Preparation of the Final Investigative Report.

In October 1993, during the 18th KLOTZ Club meeting in Stockholm, an opportunity emerged in which the post-event activities associated with the accidental detonation at the Army Munitions Factory, Steingletscher installation in the Alps, were discussed between the Swiss and United States Air Force delegates. As more information on the "engineered and geologic systems," at the accident site, were disclosed, it became apparent that the "explosive safety criteria" developed (Bakhtar, 1991) and latter verified through a series of scale model experiments (Bakhtar, 1993) under the U.S. Air Force, SBIR Program, Phases I and II, are applicable to the case to estimate the TNT equivalent weight of the stored explosives. Details of the "Bakhtar Criteria" are discussed elsewhere (Bakhtar, 1994), however, it should be pointed out that the accuracy associated with such an approach is contingent on the ability to characterize the host geologic system based on the index tests as described by Bakhtar (1989), Bakhtar and Jenus (1994).

On November 15, 1993, the accident site was re-visited jointly by the Swiss and US Air Force representatives. The purpose of this visit was to obtain site specific data on the characteristics of the geologic and engineered systems associated with the Steingletscher installation. These information were to be used in the Bakhtar Explosives Safety Criteria for estimation of the TNT equivalent weight of the stored explosives on the day that accident occurred.

The following objectives were accomplished during the site visit:

- Site geology was discussed with the Swiss Geologist, Dr. T. R. Schneider, who was retained by the Swiss authorities to compile relevant geologic information.

- Aerial inspection was conducted over the accident site using a helicopter provided by the Swiss Army.

- Ground tour was conducted to the accident site. However, access was limited to the slope toe where most of the fly rocks (fragments) post-blast were accumulated. The reminiscence of the explosive storage facility was clearly visible on the background from this location.

- Index tests were performed on several pieces of rock and a large piece of concrete which originated from the installation.

The field data and other information acquired during the site visit were taken back to the United States and used to prepare the "preliminary" report of investigation on the TNT equivalency of stored explosives at the Bakhtar Associates office in Newport Beach, California.

Tables 1, 2, and 3 show the overall information collected on site specific characteristics of the engineered and geologic systems at the Steingletscher installation destroyed during the event of November 2nd, 1992.

TABLE 1. PERTINENT PARAMETERS OF ENGINEERED SYSTEM
(USED FOR ESTIMATION OF TNT EQUIVALENT WEIGHT
OF EXPLOSIVES BASED ON BAKHTAR CRITERIA)

COMPONENTS	VOLUME (m^3)	SECTIONAL AREA (m^2)
Chamber 1	2,870	----
Chamber 2	2,180	----
Chambers (1 + 2)	5,050	----
Access Tunnel	----	19.4

TABLE 2. INPUT PARAMETERS TO BAKHTAR CRITERIA

PARAMETERS	VALUES
Overall Modulus, E	5,500 MPa
Seismic Wave Velocity, v	3,000 - 2,000 - 1,000 m/sec.
Total Chambers Volume, V	5,050 m^3
Overburden Depth, Z	50 m
Venting Characteristics, S	19.4 m^2
Initial Explosive Weight*	10 kg
k-factor	counter set = 1.225

* - Used to initiate the iteration procedure.

TABLE 1.
AND
TABLE 2.

TABLE 3. LIST OF ROCK PROPERTIES PROVIDED BY SCHNEIDER (1993).

PROPERTIES	RANGE	AVERAGE	REMARKS
$\sigma_{UNCONFINED}$	110 - 180 MPa	130 MPa	Perpendicular to Schistosity
$\sigma_{UNCONFINED}$	80 - 140 MPa	120 MPa	Parallel to Schistosity
MODULUS, E^*	$25x10^3$ - 50×10^3 MPa	38×10^3	Perpendicular to Schistosity
MODULUS, E^*	$20x10^3$ - 35×10^3 MPa	30×10^3	Parallel to Schistosity
TENSILE, T	6 - 15 MPa	10 MPa	Perpendicular to Schistosity
TENSILE, T	3 - 10 MPa	7 MPa	Parallel to Schistosity
$\phi^*_{PEAK - DRY}$	27° - 40°	34°	-----------------
$\phi^*_{RESIDUAL}$	25° - 38°	31°	-----------------
$C_{COHESION}$	1 - 2.5 MPa	1.8 MPa	-----------------
DENSITY, ϱ	2.60 - 2.70 gm/cc	2.65 gm/cc	-----------------
JRC^+	1 - 4	2	Based on Barton's Definition

* - VALUES APPEAR EXTREMELY HIGH AND REPRESENT THOSE OF INTACT SAMPLES.
\+ - JOINT ROUGHNESS COEFFICIENT.

TABLE 3.

The above data were used as input to the Bakhtar Explosives Safety Criteria, shown in the following equation, to perform a series of calculations and parametric studies for estimation of the TNT equivalent weight of explosives.

$$D = 150 \left(\frac{R}{C}\right)^{-0.52} * S^{0.89} * g^{-0.26}$$

The final results of the parametric studies are shown in Figure 13. For a fragment throw range of about 800-m the equivalent loading density of the stored explosives was calculated to be about 227 tons.

REMARKS

The preceding pages show the summary of the post accident investigation performed by the Swiss authorities and the contribution made towards estimation of TNT equivalent weight of the stored explosives by the US Air Force (YOX). Additional work is being done to complete the scope of the investigation and the findings will be presented to the explosives safety community. It is hoped that through technical exchange and enhanced cooperative works between the allied countries a trend towards improved safety for munitions storage be provided in order to prevent such unfortunate accidents from ever happening again.

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FIGURE 1.

Entrance Building before the Explosion

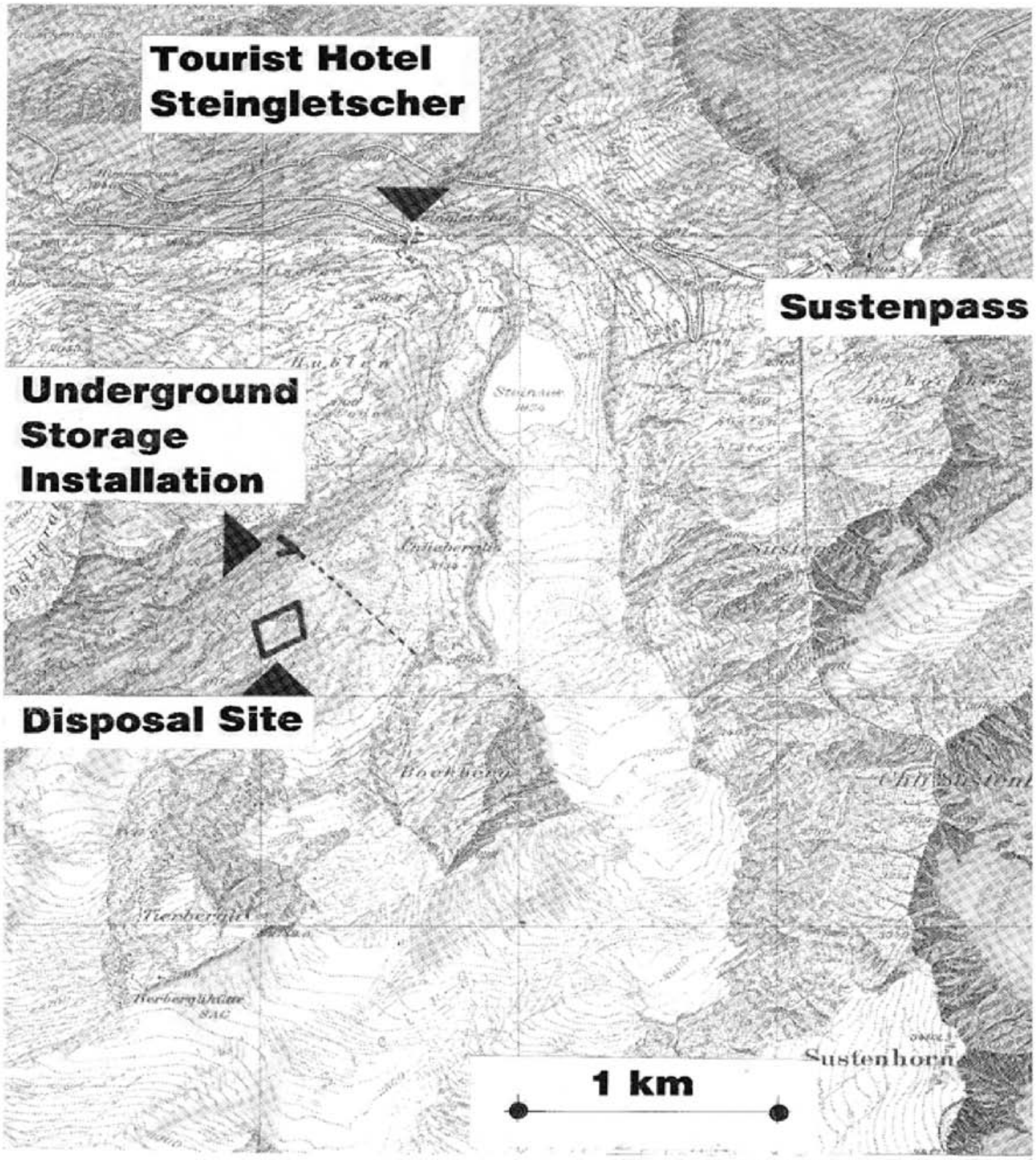
Figure 1

FIGURE 2.

Overview of the Demolition Area

Figure 2

FIGURE 3.

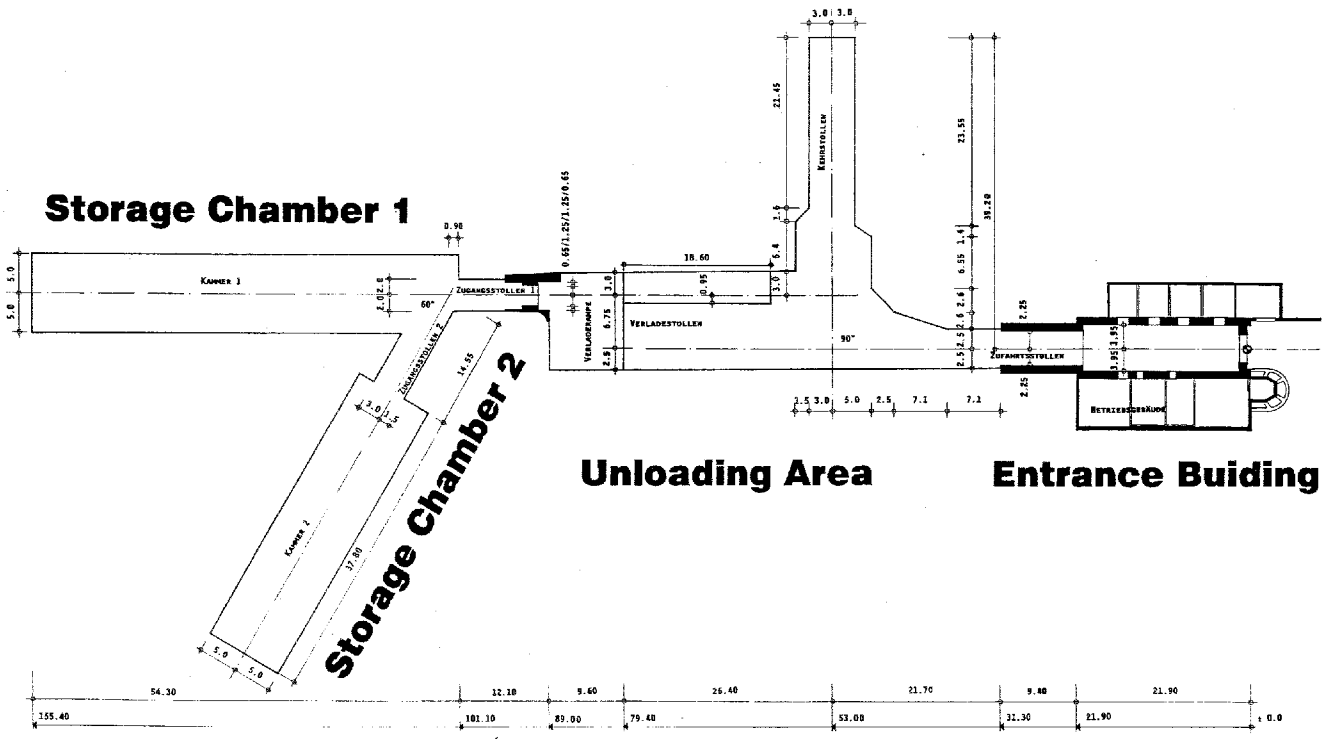


(With Permission by the Swiss Federal Office of Topography dated July 5, 1994)

Location of the Magazine "Steingletscher"

Figure 3

FIGURE 4.

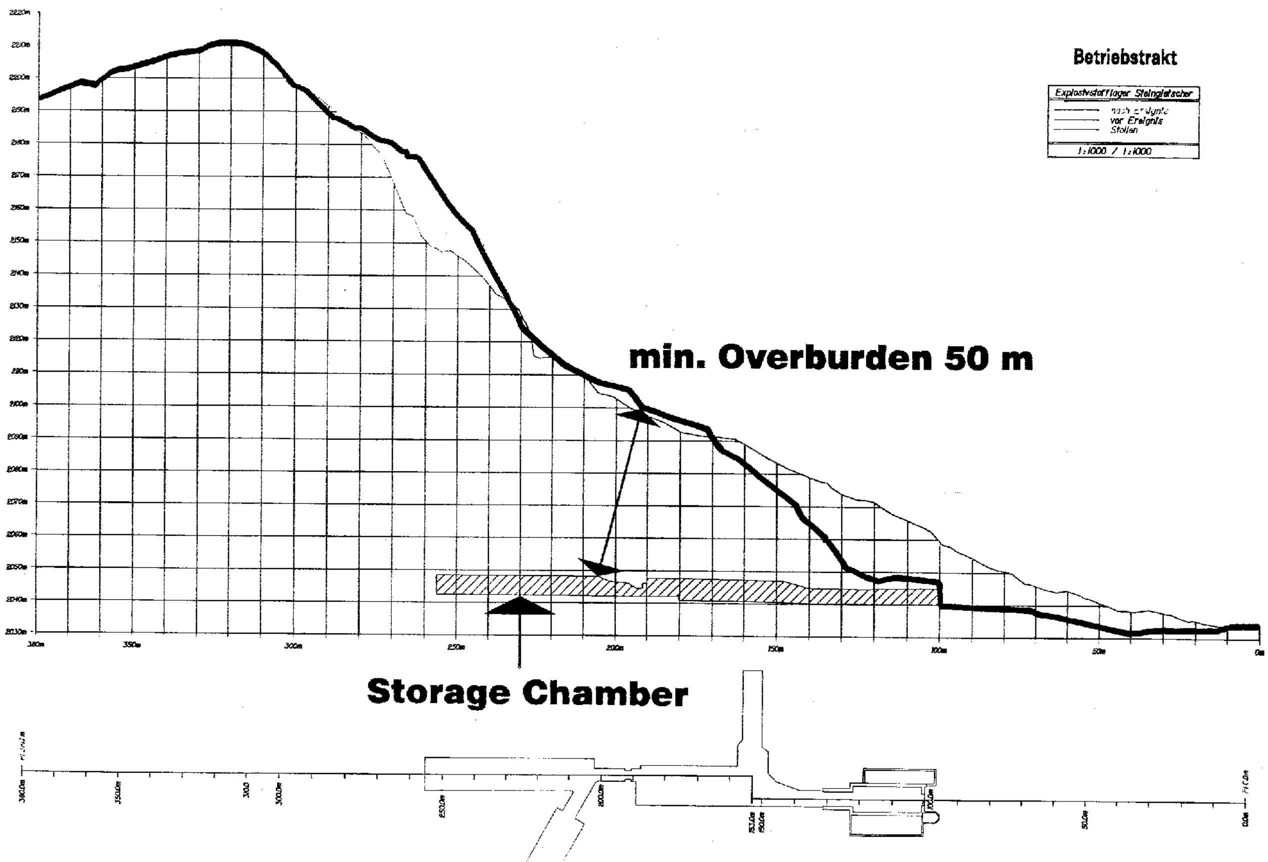


0 50 m

Magazine Layout

Figure 4

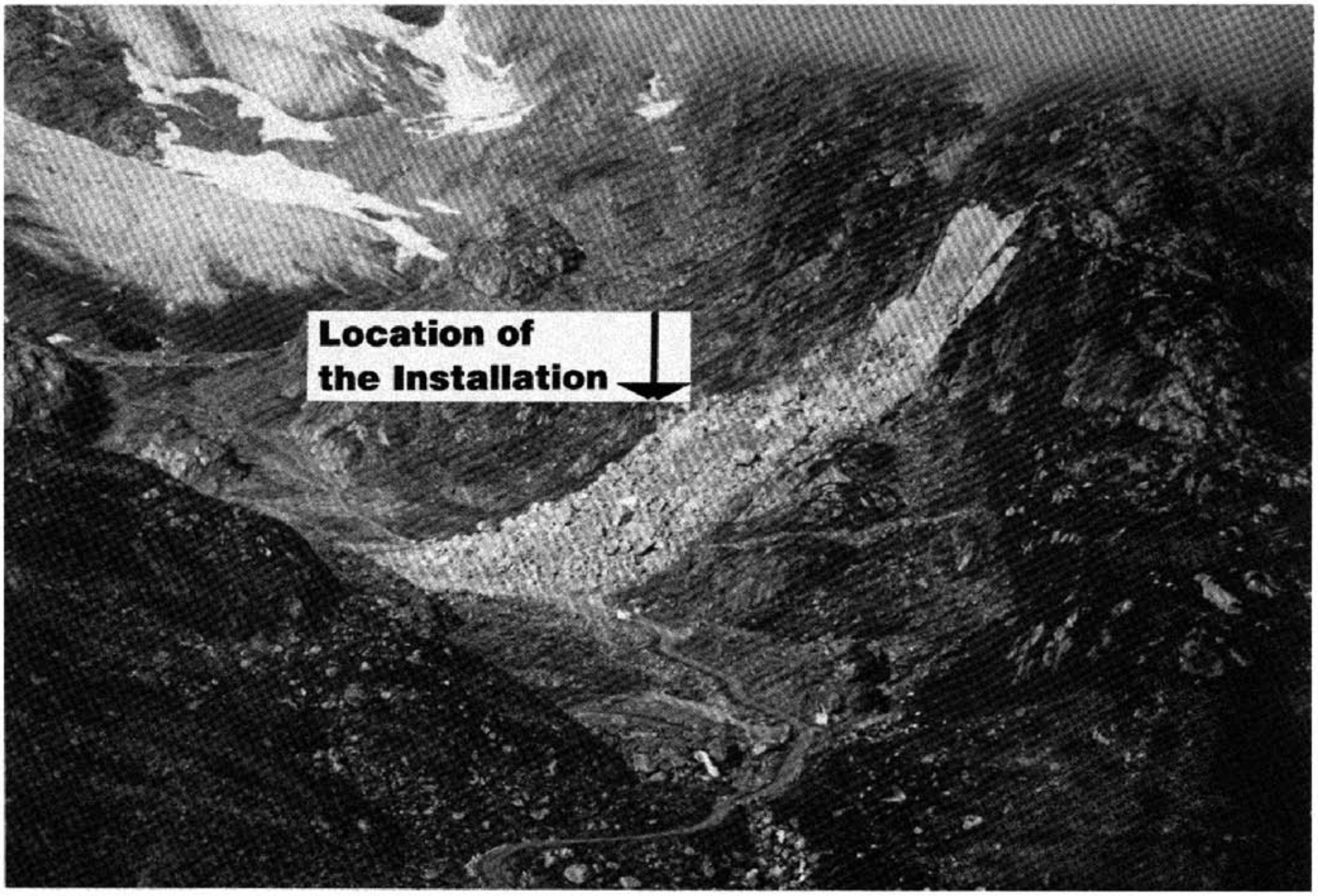
FIGURE 5.



Longitudinal Section before and after the Event

Figure 5

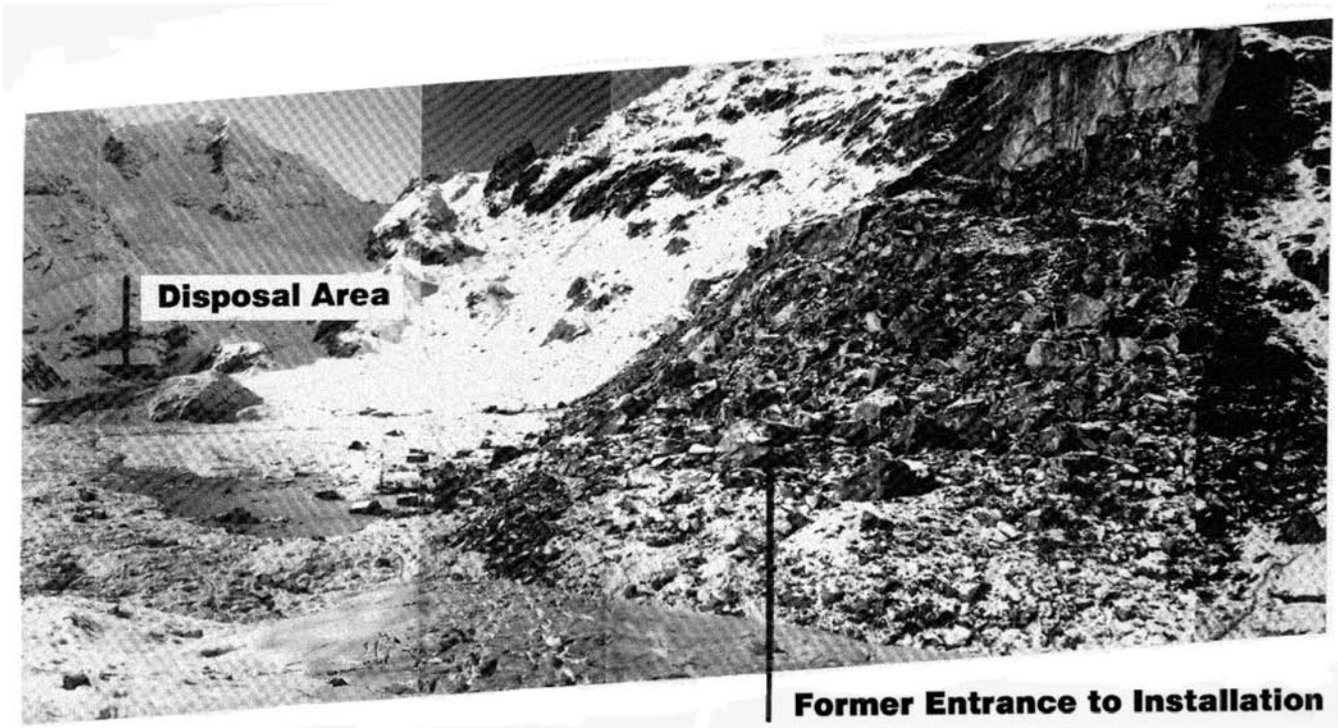
FIGURE 6.



Overview of the Scene after the Explosion

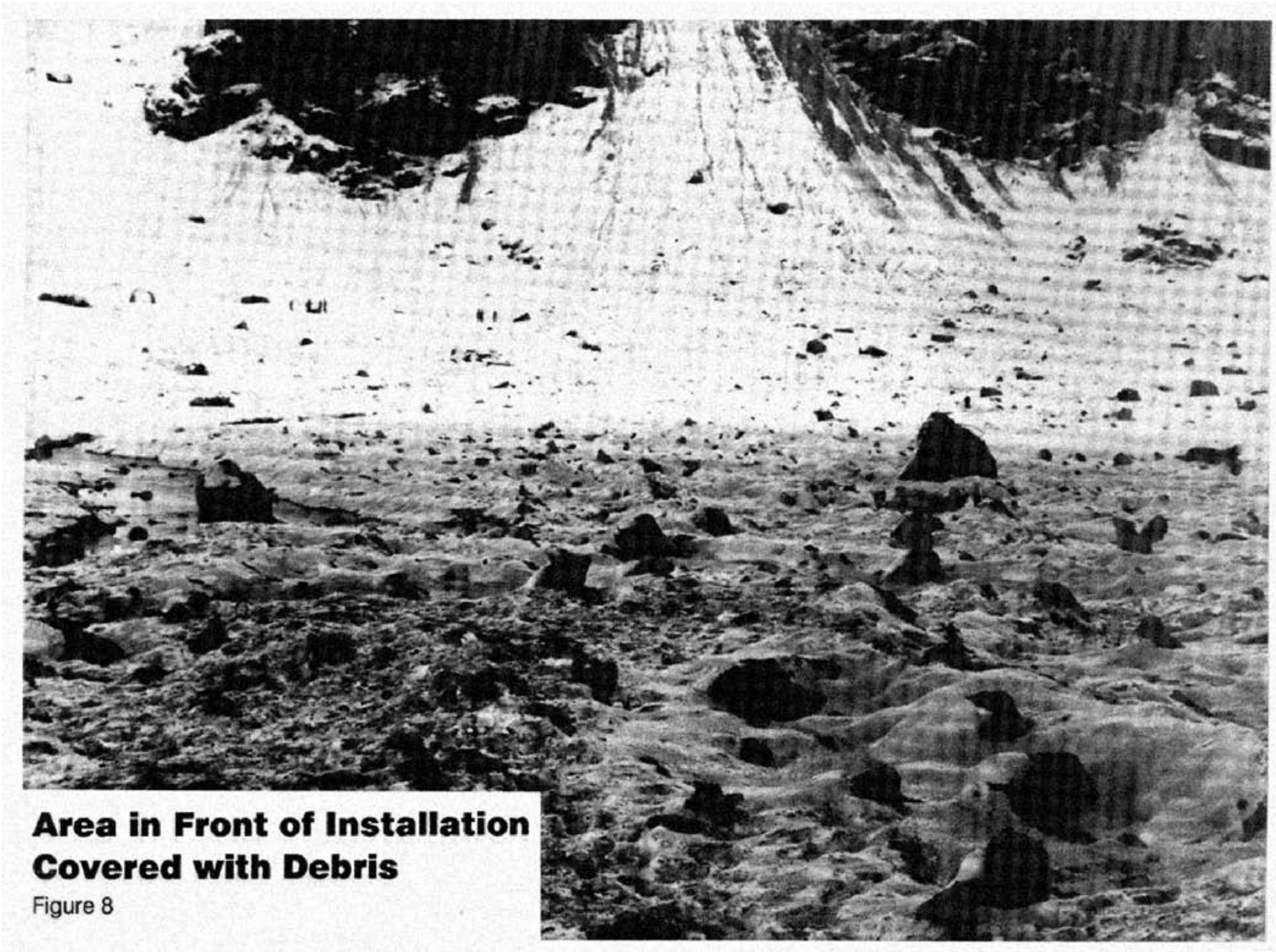
Figure 6 (Taken seven months after the event)

FIGURE 7.



Site of Installation
two Days after Explosion
Figure 7

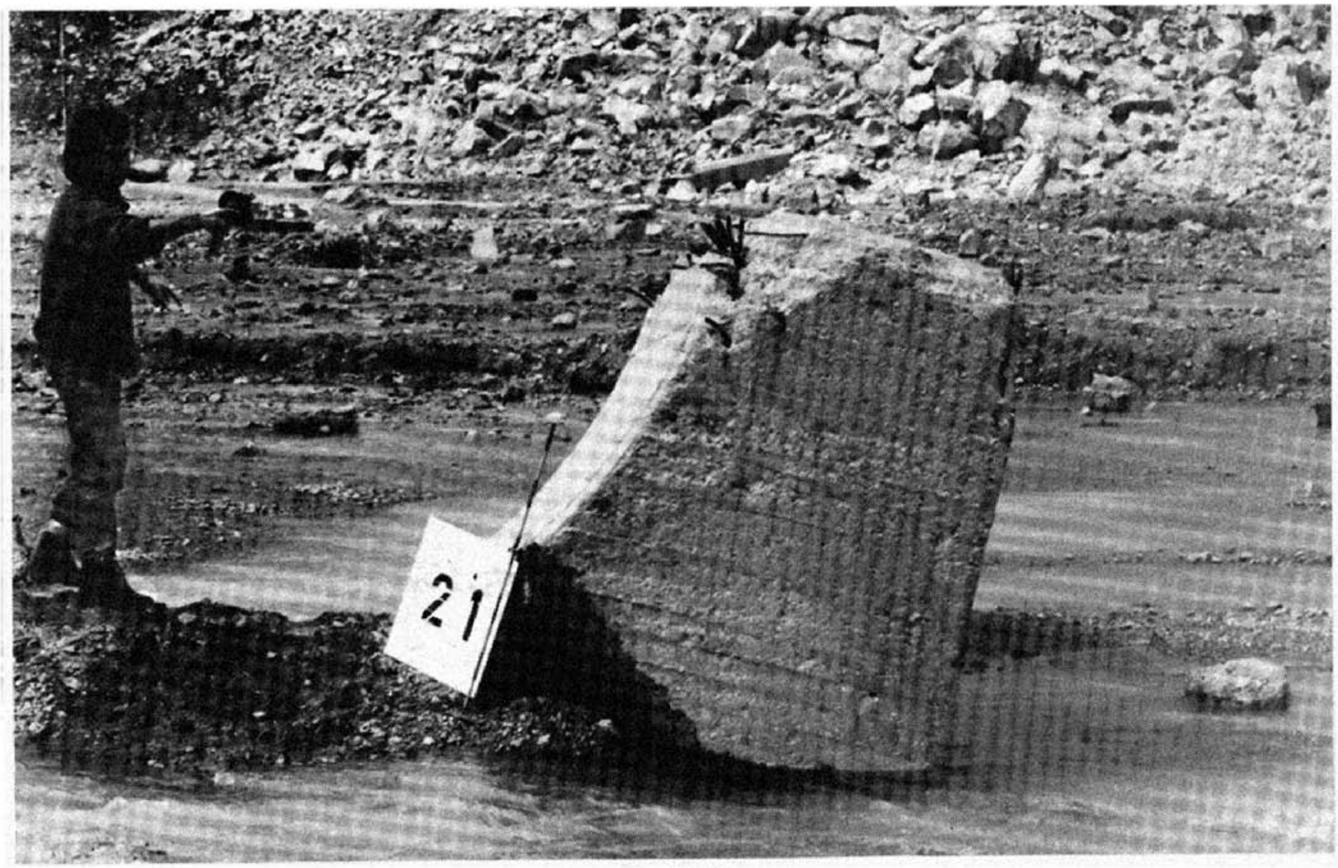
FIGURE 8.



Area in Front of Installation Covered with Debris

Figure 8

FIGURE 9.



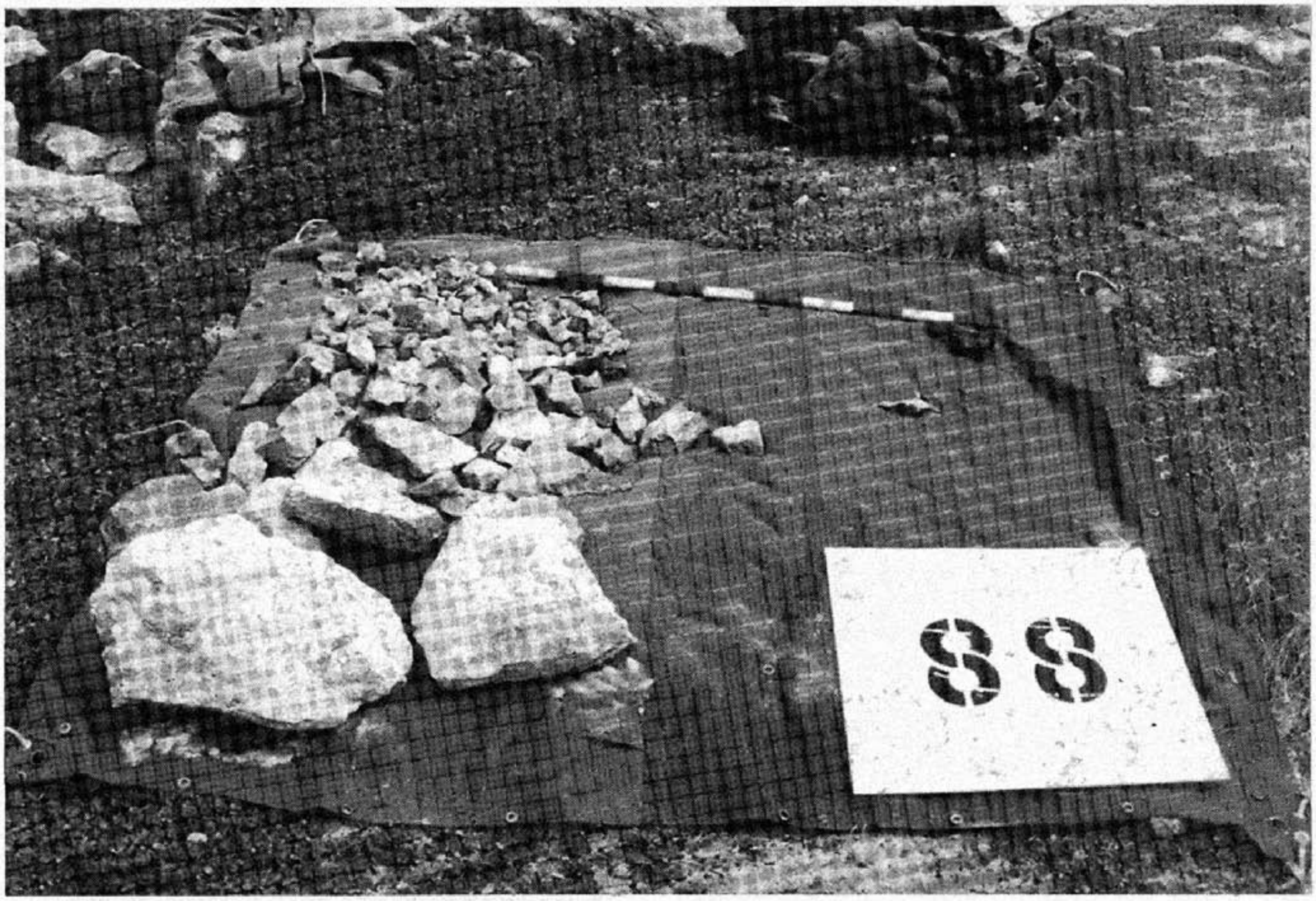
Concrete Block from Entrance Building
Weight 15 tons, 370 m from Original Place

Figure 9

FIGURE 10.

Debris Collection Areas
Foreground Debris No 21 (Figure 9)
Figure 10

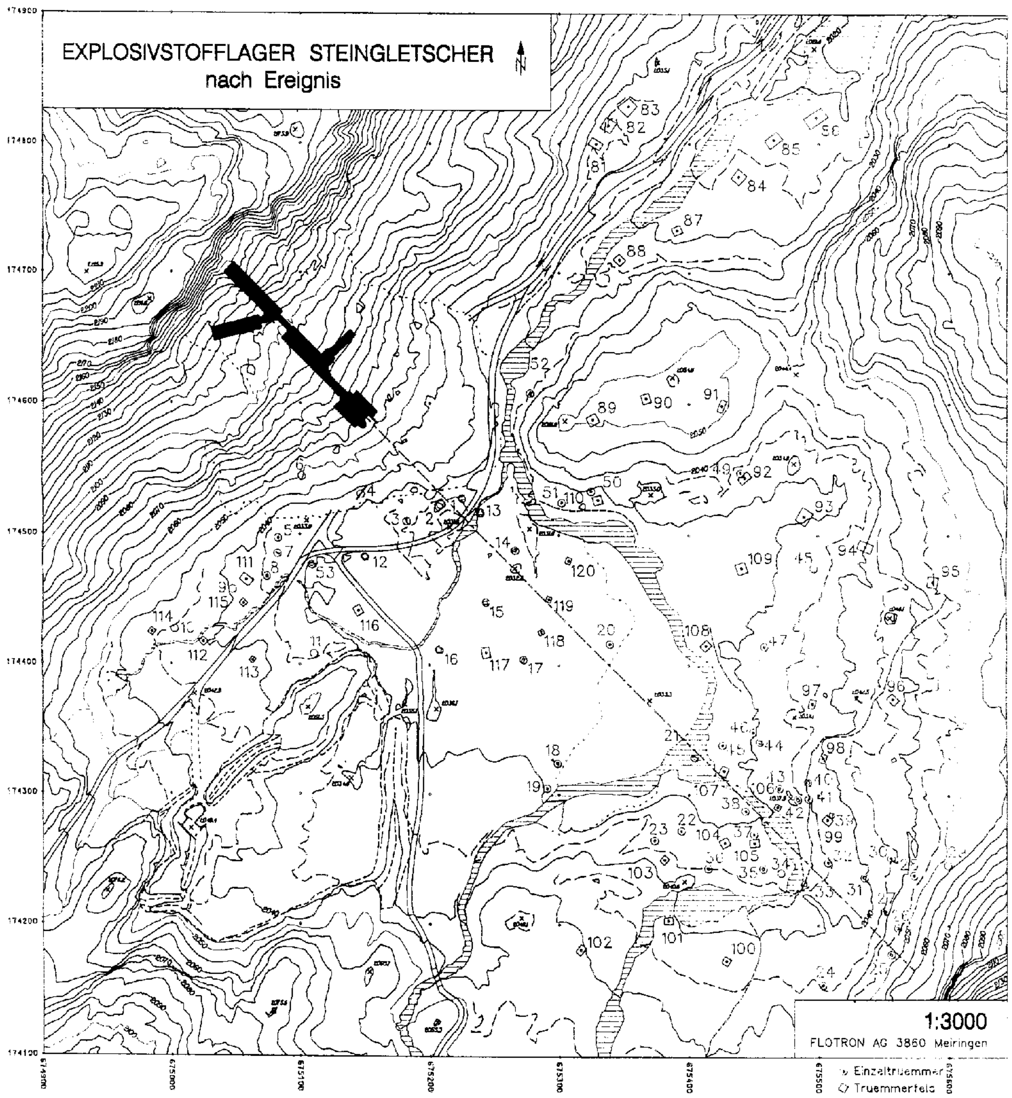
FIGURE 11.



Debris from a "Collection Area"

Figure 11

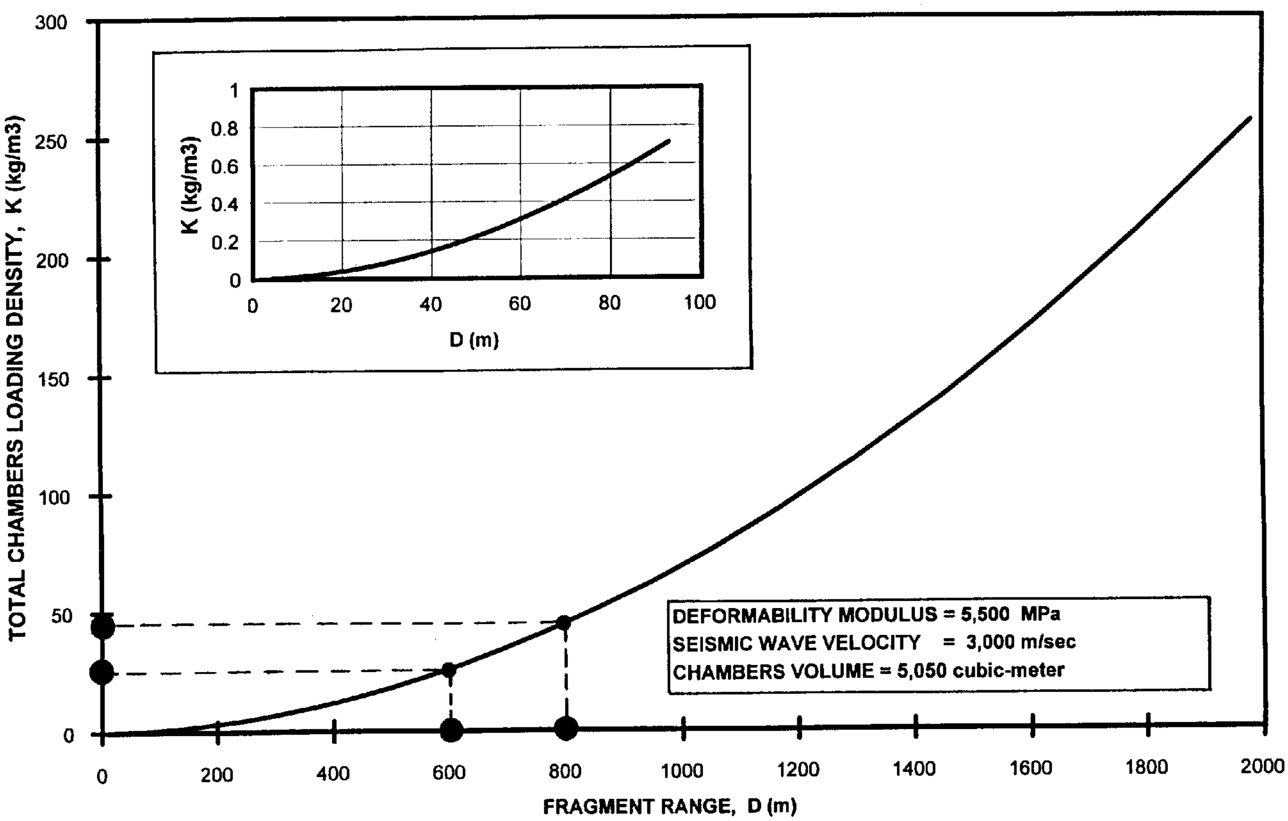
FIGURE 12.



New Area Map with Identified Objects

Figure 12

FIGURE 13.



Variations of Loading Density with Fragment Range

Figure 13